GUIDELINES FOR THE PREVENTION AND ELIMINATION OF FOREIGN OBJECT DAMAGE/DEBRIS (FOD) IN THE AVIATION MAINTENANCE ENVIRONMENT THROUGH IMPROVED HUMAN PERFORMANCE

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1 INTRODUCTION

Foreign Object Damage (FOD) costs the aviation industry millions of dollars every year (Bachtel, 1998; Henderson, 1996; Tuthill, 2000)[4,12,23]. This financial impact comes from direct costs such as damage to engines or airframes as well as indirect costs such as; flight delays, cancellations, and lost revenues; schedule disruptions; and additional work by employees. More significant than the financial impact, however, is the safety impact and potential lose of human life. Aviation safety is of paramount importance and Foreign Object Debris and the resulting Foreign Object Damage put the safety of the flying public at risk. According to a recent survey by the aviation industry, Foreign Object Damage was ranked as the most likely potential ground-based cause that could lead to a catastrophic aviation event. This begs the question: Why do FOD errors occur, and how can they be prevented?

The aviation maintenance environment is a highly complex system with the Aviation Maintenance Technician (AMT) at its center. The AMTs must apply their specialized knowledge, skills and experience to tightly controlled procedures while interfacing with a demanding environment with organizational, environmental and work pressures. Errors and accidents involving Foreign Objects (FO) occur simply as a result of this complexity, and according to Weick (1987)24, the human, or AMT, is not sufficiently complex to anticipate the problems generated by the system. It is critical, therefore, to have an understanding of the human factors of the system, and to address those human factors through both proactive as well as reactive measures. Through a grounded understanding of the human factors involved in FOD, the industry can provide the best guidance to eliminate existing FOD problems and prevent future FOD occurrences.

To address the problem of FOD, the Federal Aviation Administration, Office of Aerospace Medicine, funded a project to research reducing FOD in the aviation maintenance environment through improved human performance. Over the years, many organizations within the aerospace industry have developed FOD prevention programs that comprise time-tested methods. The methods involve implementation and training on technical procedures to FOD prevention. Though successful, this linear approach fails to consider the human interaction with the system (hardware, software, environment, organization, etc.), which unfolds in a non-linear manner.

These guidelines provide a broader human factors approach to FOD prevention through application of human factors best practices. As illustrated in Figure 1, the guidelines give two distinct approaches to the concept of FOD prevention through improved human performance: 1) proactive measures to prevent FOD, and 2) reactive measures to correct problems and prevent reoccurrence. The delineation between the technical guidance and human factors guidance is often blurred. For example, training may be considered a human factors intervention strategy as well as a technical solution. For the sake of continuity and completeness, these guidelines will include, as appropriate, some technical guidance or will reference where these technical approaches may be found.

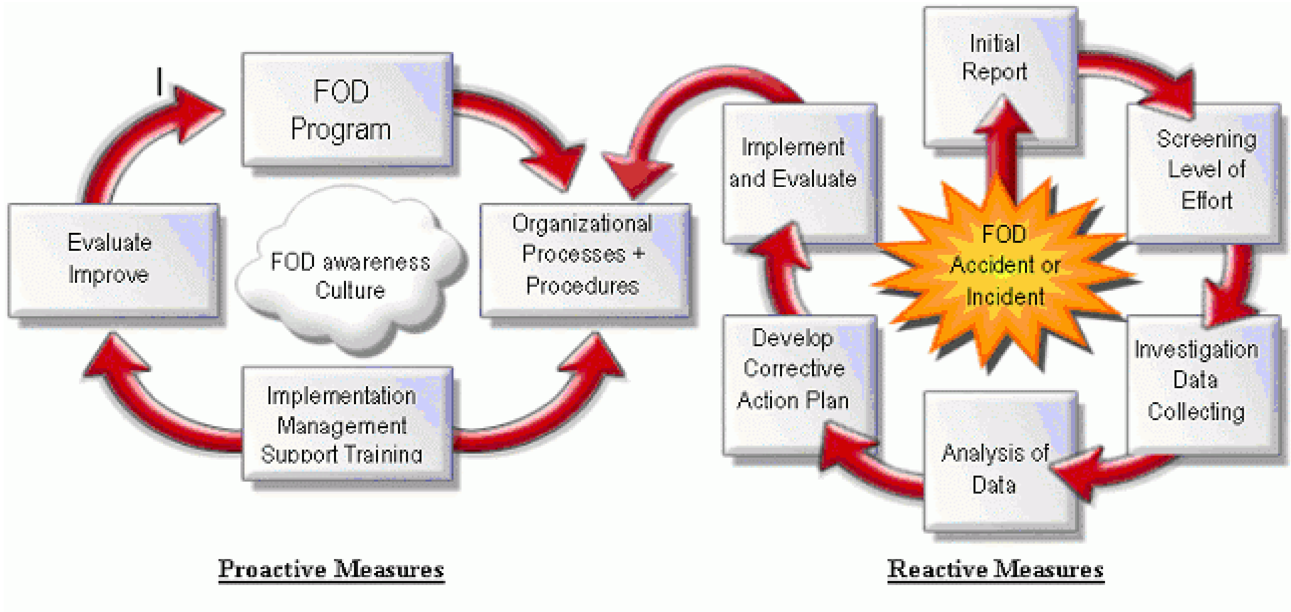

Figure 1 – Proactive (preventative) Measures and Reactive (corrective) Measures

1.1 Scope

Foreign Object Damage/Debris has been recognized as a serious problem throughout the aerospace industry including manufacturing, maintenance, operations, etc. Though many of the FOD prevention practices are applicable across the industry, the scope of these guidelines is limited to the prevention and elimination of Foreign Object Damage and Debris in the aviation maintenance environment. By focusing on the maintenance environment, the guidelines do not address FOD due to biological elements (birdstrikes, animal ingestion, etc.), lightning and other weather related events (hail, ice, etc.), and damage from ground support equipment.

In addition, these guidelines will not address FOD as it relates to aircraft tire maintenance and airport operational practices. Though this is a critical FOD issue, examination of databases from various airlines failed to identify any significant FOD to aircraft tires in a maintenance environment. In addition, there are several FAA publications that address FOD to tires either directly or indirectly (Air Carrier Operations Bulletin No. 8-93-5 – Tire Failure on Transport Category; AC 25-22; AC 150/5380-5B Debris Hazards at Civil Airport).

Finally, there are a number of devices and tools on the market that can enhance a FOD control program within the aviation maintenance environment (e.g., tool storage, tool control, lost-tool finders, FOD sweeper, vacuums, FOD cans, organizers, etc.). It is not the purpose of this publication to recommend the purchase of any specific FOD control system. The purchase and use of all or part of such systems will be at the discretion and needs of the individual organization, and dictated by the requirements of their FOD program.

1.2 Definitions

The following is a list of definitions commonly used in discussing Foreign Object Damage and human error. These definitions will be used throughout the Guidelines.

Active Failure – A type of human error whose effects are felt immediately in a system.

Corrective Action Plan – A structured course of action that is derived from data and information collected during a FOD investigation and root cause analysis, and if implemented correctly will likely correct the immediate problem as well as prevent a reoccurrence of the problem.

FOD Point of Contact (POC) – An individual who has the authority and responsibly to organize, coordinate, develop, implement, monitor, and ensure that the efforts to eliminate FOD are carried out throughout the organization. See section 2.1.2 for further requirements of the FOD POC.

Foreign Object (FO) – Sometimes referred to as Foreign Object Debris - Any alien substance or article that invades any component of the aircraft and which causes or has potential to cause damage to aircraft, persons, equipment, or otherwise diminish safety.

Foreign Object Damage (FOD) - Any damage that has occurred to aircraft, vehicle, or persons, which can be attributed to an alien substance or article (FO) that has invaded any component of, on, or in an aircraft.

Foreign Object Elimination (FOE) – A program or process used to assure a FOD free product or system. Synonymous with FOD and Tool Control and FOD Prevention.

Human Factors – The scientific discipline where the discovery and application of information about human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use (Sanders and McCormick, 1993).[20]

Latent Failure – A type of human error whose effects may lie dormant until triggered later, usually by other factors, or an ever-present condition or set of conditions in an environment or in an organization that has the potential to trigger an active human error. The latent failure sets the human up for an error.

Tool Control – Any formal system designed to assure that each tool that goes onboard the aircraft is removed and accounted for.

2 IMPLEMENTING PROACTIVE MEASURES

According to the National Aerospace Standards (NAS 412)[1], most foreign object damage is attributable to four factors: poor housekeeping, facilities deterioration, improper maintenance, and inadequate operational practices. This document recognizes these areas, and from a human factors perspective additionally addresses management and organizational interaction and support (employee buy-in and management commitment), FOD awareness, FOD training, and finally FOD audits and inspections. Figure 2 illustrates how these human factors elements add towards the creation of a pervasive FOD awareness culture.

All of these factors, taken together, make up the proactive measures that can be used to eliminate and prevent foreign object damage in the aviation maintenance environment. The following sections provide guidelines for implementing the proactive measures. These guidelines are not standards and as such should be modified and enhanced to fit the particular organization.

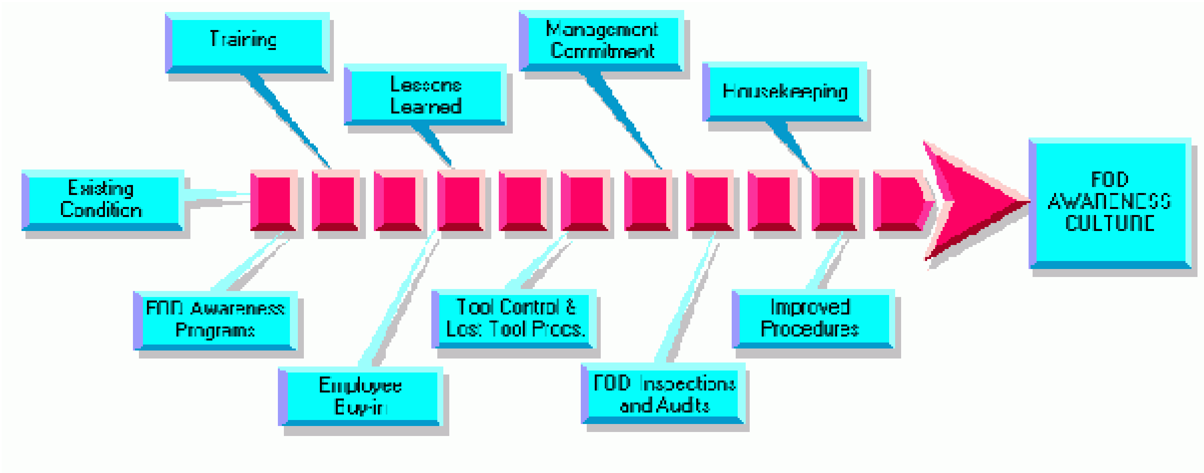

Figure 2 – Human Factors Elements of a FOD Awareness Culture

2.1 Management Support

Management support is key to the success of any FOD program that is developed. Management support should be more than lip service (i.e., words without actions). Rather, it should include the creation of a FOD prevention/elimination program with adequate funding, the appointment of a responsible point of contact with authority to carry out the FOD program, and the full support and encouragement of a FOD prevention culture that crosses all boundaries within the organization. As a final element, management should recognize and support the National Aerospace FOD Prevention, Inc. (NAFPI) and the work this national organization is doing to eliminate FOD from the aerospace industry as a whole. The following sections provide guidelines for each of these elements.

2.1.1 Create a FOD Prevention Program

The FOD Prevention Program should provide clear and precise policy and procedures to prevent and eliminate FOD in the organization. The program should address such items as:

- An understanding of the importance of FOD elimination – How does FOD prevention affect safety, quality, costs, and customer satisfaction?
- The vision of the FOD Prevention Program
- The goals that need to be achieved and the time frame to achieve them
- Measurement or Benchmarking – How does the organization compare with other similar organizations? What measurements will be made to demonstrate progress, how will they be made, what are the starting conditions?
- Organization – Who will manage the program? What support will be available? How will the support be organized?
- Policies and Procedures – What policies and procedures exist? How are they disseminated or published? How will continuous process improvement be achieved?
- Feedback Procedures – How will information concerning FOD successes or failures be communicated back to the maintenance technicians and managers?
- Investigations of incidents and accidents – How will accidents and incidents be reported and investigated? What data will be collected, where will it be stored, and how will it be analyzed? How will the data analysis affect the future direction of the program?

2.1.2 Establish a FOD Point of Contact (FOD POC)

A FOD Point of Contact must be established to develop, implement, and monitor FOD plans and programs. The POC should have the responsibility with sufficient authority to identify and implement FOD preventative measures whenever and wherever required. Table 1 lists some of the FOD POC's responsibilities.

Table 1. Potential Responsibilities of the FOD POC

q	**Develop and implement FOD training to include approval of training curricula, designation of training personnel, and review of training records.**
q	**Maintain currency with FOD prevention measures through interaction with FOD POCs at other organizations and through active involvement with National Aerospace FOD Prevention Inc. (NAFPI).**
q	**Organize and promote a FOD committee to address FOD prevention and elimination in the organization.**
q	**Develop and implement a FOD prevention/elimination program for the organization, and the assurance that all procedures are implemented throughout the organization.**
q	**Develop, encourage, and maintain FOD buy-in from management and the work force.**
q	**Assuring that written FOD prevention procedures are adequate and that they are published and disseminated.**
q	**Establish or maintain quality assurance through ISO 9001 compliance or other similar programs.**
q	**Review and assess published procedures on a regular basis to make continuous improvements.**
q	**Evaluate reported Foreign Object Damage/Debris to determine how, when and why it occurred.**
q	**Ensure that FOD audits are conducted on a regular basis and that the results are examined and analyzed for potential improvements in processes and procedures.**
q	**Ensure that all FOD incidents and accidents are thoroughly investigated and that the results are maintained in a FOD database for analysis.**
q	**Ensure that any corrective actions resulting from a FOD incident/accident investigation are implemented.**
q	**Provide FOD information to all personnel at all levels in the organization.**
q	**Report FOD, as required, to regulatory authority (i.e., FAA Flight Standards National Field Office).**

2.1.3 Establish and Maintain a FOD Prevention Culture

The culture of an organization is the collection of beliefs, norms, attitudes, roles, as well as social and technical practices that are shared by individuals within an organization (Pigeon 1991)17. A good safety culture focuses on minimizing dangerous and injurious conditions that may affect not only the employees or the organization. A more important result of a good safety culture is improved safety for the public at large. Thus culture is an important human factors element in maintaining a FOD free environment. It is also a concept that crosses all organizational boundaries and permeates all human factors interventions that may be employed.

The aircraft maintenance technician's attitudes towards FOD will be a reflection of the values and beliefs that management places on FOD prevention or elimination. In other words, members of the organization will try to meet the perceived expectations of the management. Thus, it is incumbent on management to establish and maintain a FOD prevention culture within the organization.

Senior management should place strong emphasis on FOD elimination as part of the overall strategy of risk management. Those in management positions should foster a climate of open discussions and feedback on the prevention of FOD.

Management should appoint a FOD Point of Contact (FOD POC) that will have authority and responsibility to develop, implement, direct and carry out a comprehensive FOD program. In addition, management should also establish and support a FOD committee with the FOD POC as the chairperson. The FOD committee should meet on a regular schedule, and the membership should, at a minimum, have representative from the following areas:

- Safety
- Engineering
- Security
- Training
- Logistics
- Operations
- Quality Control
- Management
- Other associated organizations (Food Service, Airport, etc.)

2.1.4 Actively participate in NAFPI

The National Aerospace FOD Prevention Inc. (NAFPI) is a nonprofit educational organization dedicated to the elimination of FOD in the aerospace industry. Formed in 1985, NAFPI provides information about current practices and technological advancements regarding awareness, detection, and prevention of FOD.

NAFPI is a key resource to those who are concerned about FOD. The volunteers at NAFPI disseminate information through three major vehicles.

1. Quarterly newsletters, which contain articles and success stories contributed by members of the organization.

2. A web site (http://www.nafpi.com)

3. Annual conferences that feature key international speakers and interactive learning sessions hosted by industry volunteers who share their experiences on a variety of FOD related issues.

2.2 FOD Awareness

Publicity and awareness is another key element in an effective FOD prevention program. FOD awareness should be maintained through the use of banners, posters, signs, videotapes, and bulletin board notices. FOD awareness activities include:

- Make FOD announcement/discussions a part of meetings.
- Create incentive programs designed to reward individuals or departments for their FOD reduction effort.
- Solicit involvement from vendors and contractors to promote FOD awareness.
- Promote contests such as a best FOD poster or slogan contest.
- Publish regular FOD articles for company newsletter.
- Disseminate FOD alerts and bulletins.
- Display improvements or progress towards obtaining FOD free objectives.
- Establish FOD awareness week/month.

2.3 FOD Education & Training

All maintenance personnel should receive training in FOD prevention and elimination in order to increase employee awareness as to the causes and effects of FOD. Effective training should emphasize good work habits through structured work disciplines, and promote active involvement in FOD awareness programs. FOD subjects that should be addressed during training include:

- Review and explanation of the organization’s FOD program, policies, and procedures
- Causes and effects of FOD with real life examples and the cost impacts
- Safe workmanship practices and individual responsibilities
- Proper storage, shipping and handling of material, components, equipment, personal items, and tools
- Accountability and control of tools, materials, and hardware
- Continual vigilance for potential sources of FOD and techniques to control debris
- FOD clean-up strategies (e.g., FOD walks, sweeps, etc.)
- Housekeeping (cleanliness in the work area)
- Cleaning and inspection of components and assemblies
- How to report a FOD incident or near mishap

2.3.1 Technical FOD Training

In addition to the general FOD training required for all employees, contractors and subcontractors, the maintenances technician should receive additional training focused on the technical aspects of FOD prevention and elimination. This technical FOD training may include:

- Correct methods to clean and maintain fuel filters
- Procedures for refueling

- Procedures for disposing of small pieces of maintenance material (i.e., clipped pieces of safety wire)
- Proper clothing and attire (jewelry, buttons and snaps, loose fitting clothing, etc.)

2.3.2 Initial and Recurrent Training

As part of their initial orientation, all new and rehired employees should receive FOD prevention indoctrination. This initial training should also be a requirement for contactors and subcontractors. In addition, it is recommended that the organization stipulate that no maintenance crewmember or supervisor is allowed to work on an aircraft of its sub-assemblies until they have received FOD training.

Records should be maintained on all personnel receiving FOD training. Additional recurrent training should be required at regular intervals (annually or bi-annually) or as requested. Recurrent training can be provided through Computer-based Training (CBT) or over the Web (WBT).

2.4 Housekeeping

The responsibility of proper housekeeping resides, not only with management but also with the individual as well. If you see debris, don't walk over it – pick it up and dispose of it properly.

2.4.1 General

As part of the FOD prevention and elimination program, FOD receptacles should be placed in easily accessible locations throughout the maintenance environment. The receptacles should be painted or marked for easy recognition. In order to prevent FOD migration from these receptacles, they should be of appropriate size and enclosed to prevent overflow. If the receptacle is located outside the hangar area, then they should be watertight to prevent leaching. Finally, the receptacles should be emptied on a regular basis as well as when requested.

There should be regularly scheduled FOD walks of hangar bays, aircraft ramps and aprons. Consideration should be given to using specialized brooms, magnets, and vacuum-type machines to clean areas. If brooms or sweepers are used, NAFPI FOD Prevention Guidelines (2000)15 recommends that you do not use brushes with metal bristle or spines.

2.4.2 Individual

A clean working environment is fundamental to FOD prevention. In the aviation maintenance environment, individuals must follow the concept of "clean as you go."

- When finished or when work cannot continue, clean the immediate work area and workstands.
- Pick up debris that has the potential to migrate into an out-of-sight or inaccessible location.
- Clean the immediate area after work is completed and before inspection.
- Clean at the end of each shift.
- Keep food and beverages out of the work area.
- Return cleaning equipment, hoses, drop lights and power cords to their proper storage area.

2.5 Maintenance Activities

The fundamental process to prevent foreign object damage it to perform all maintenance tasks "by the book." This includes all procedures from removing excess grease from a component to capping all aircraft ports and disconnected lines with approved material. There are a number of guidelines available to maintenance organizations to prevent FOD, and the following sections, though not all inclusive, address these guidelines in four major areas; maintenance, material handling, tool control and accountability, and use of state-of-the-art equipment to find and remove FOD.

Not all the guidelines offered in the following section are related to human factors issues. As a result, this document provides both types of guidelines. When technical FOD guidelines are provided in another document, reference is made to the material.

2.5.1 Maintenance Guidelines

- Plug, cap or cover aircraft ports, lines, hoses, and ducts prior to maintenance to prevent migration of debris into critical airworthiness areas.
- Cover or otherwise protect equipment that is sensitive to potential FOD damage. This includes covering engine inlet and exhaust during maintenance of systems not requiring access to the engine area.
- Easy to see FOD receptacles should be placed throughout the maintenance environment and should be emptied regularly and as required (see Housekeeping, section 2.4.1).
- Never let a FOD receptacle overflow.
- Inspect and clean aircraft and surrounding area throughout maintenance/modification.
- If an item is dropped into a critical airworthiness area, it should be located and removed before proceeding with the task. If the item cannot be found, the technician should report the matter to the supervisor. The item should be accounted for before the aircraft is released.
- All final closures should be inspected for FOD.
- Keep to a minimum all hardware taken aboard the aircraft.
- Use tote trays, sacks, boxes, etc. to store/carry/transport tools and equipment in order to minimize spillage. Tool trays should have lids.
- Inspect for extraneous material as part of any assembly step.
- Prior to engine run, conduct a FOD walk in front of the intake and behind the exhaust area of the engine.
- Check aircraft tires for foreign objects.
- Report any damaged paving.
- WHENEVER YOU SEE DEBRIS – PICK IT UP AND DISPOSE OF IT PROPERLY.

2.5.2 Material Handling

Material handling, include consumables such as issued apparel; glue, paint, and sealant; rags; sandpaper, brushes, and applications; and stock items (i.e., rivets, washers, fasteners, etc.). In addition, packaging is also considered in material handling. The National Aerospace Standard (NAS 412)1 provides guidelines for material handling and parts protection. These guidelines address control techniques, material characteristics, and the visual inspection of the condition of the material and parts. From a human factors perspective, it is important to consider the visibility of the material used during a maintenance task so that the material itself does not become FOD. Whenever possible, the color of the packaging should be in contrast to the background. Also, the use and disposal of consumables should be included in the task procedures.

2.5.3 Tool Control and Accountability

The maintenance technician should avoid relying solely on visual inspection of the work areas to account for tools used during a maintenance task. Sometimes it is difficult to spot a tool when its color blends into the background of the work area. Therefore, a positive tool control program is strongly recommended. Properly designed procedures for tool control and accountability are designed to preclude Foreign Object Damage. Though there are a number of guidelines available for tool control and accountability, the final responsibility lies with the individual who brings these items into the work area. Table 2 provides a list of ten important components of tool control.

Table 2. Ten Points for Tool Control (Eulaine Eri 1998)9	
1)	**The individual has primary responsibility for tool control. The supervisor should have the responsibility to ensure that the user is both trained and aware of tool control processes and procedures.**
2)	**Tool control should be in effect in designated flight hardware/FOD sensitive areas.**
3)	**Tool storage should be clean and organized for expeditious inventory. Also, there should a listed inventory that matches the contents.**
4)	**All tools should be individually identifiable, and be traceable to their assigned storage location by the user.**
5)	**Lost tools should be reported immediately and a thorough search initiated. If a tool becomes unserviceable, it should be reported and exchanged one-for-one.**
6)	**Tools should not be transferred or loaned from one element or individual to another without proper documentation.**
7)	**Tools must meet identified specifications to perform the function.**
8)	**Users should minimize the number of tools taken into flight hardware to the greatest extent possible.**
9)	**Tools should always be contained and transported appropriately.**
10)	**Contractors and support personnel with their own tool control should meet the above stands at a minimum.**

2.5.4 Use of Borescope, X-ray, and other State-Of-The-Art Equipment for FOD Inspection and Retrieval

Borescopes, X-ray, and other state-of-the-art equipment are used in aircraft and engine maintenance programs to reduce or eliminate the need for costly teardowns. Aircraft turbine engines have access ports that are specifically designed for borescopes. Borescopes are also used extensively in a variety of aviation maintenance programs to determine the airworthiness of difficult-to-reach components. Typically, borescopes are used to inspect interiors of hydraulic cylinders and valves, inspect for cracked cylinders in aircraft reciprocating engines, inspect turbojet engine turbine blades and combustion cans, verify the proper placement and fit of seals, bonds, gaskets, and subassemblies in difficult to reach areas.

As it relates to these guidelines, the aforementioned equipment may be used to assess Foreign Object Damage (FOD) in aircraft, airframe, and powerplants. In addition, they may also be used to locate and retrieve foreign objects in engines and airframes.

2.6 FOD Inspection and Audits

Aircraft arriving at a maintenance facility should be inspected for Foreign Objects. If FOs are discovered, the FOD POC should be notified and the incident should be investigated (see Section 3.0)

As part of his duties and responsibilities, the FOD POC should ensure that FOD audits are conducted on a routine basis. Auditors may be selected from within the organization, and their auditing duties should be a part of their normal work duties. Auditors should not inspect their own department. As part of FOD inspections and audits, the FOD POC should:

- Conduct FOD audits on a regular basis
- Develop and use a Foreign Object Audit Form or Checklist to verify compliance with FOD policies and procedures
- Use audit results as feedback to all employees for continuous improvement
- Identify needs for training or other human factors interventions

FOD audits should provide a review of existing conditions as well as recommendations for improving the enhancing debris control. The audit results may be used to develop corrective actions programs and to provide improvements to FOD training programs.

3 REACTIVE EFFORTS

Typically, individuals who work in the aircraft maintenance environment would not intentionally cause Foreign Object Damage. In fact, most mechanics take pride in their work and work environment, and they try to perform their duties to the best of their abilities. Unfortunately, latent and active failures do occur. When there is a FOD incident or accident, it must be identified and confronted in a timely fashion in order to prevent a future occurrence.

When there is a failure or malfunction of an aircraft component that is caused or suspected to have been caused by a foreign object, it is recommend that the FOD POC initiate an investigation. The following sections will provide suggest guidance on FOD incident/accident investigation and remediation.

The following steps are provided as a guide to reactively respond to a FOD accident or incident.

. Conduct an initial screening to determine level of effort

. Investigate all actual and potential FOD accidents and incidents

. Analyze data

. Develop and implement corrective action(s)

5. Implementation and evaluation of corrective action(s)

Each step is described in detail in the following sections.

3.1 Determine Level of Effort

No organization has unlimited funds, and therefore the level of effort to investigate a potential or actual FOD incident/accident needs to balance the effect on maintenance operations against the financial impact on the organization. To help determine the level of effort for an investigation and analysis, Anderson and Weir (1999)3 suggest an initial screening of any issue into one of four levels of significance. Table 3 provides the significance determination level modified for FOD in the maintenance environment. The characteristics listed in the table are not inclusive but rather a guideline for significance determination. As noted by Anderson and Weir (1999)3, the screening characteristics should be expanded or modified based on experience and the particular organization.

The four significance levels are listed in order of severity starting with the most significant to trends only. A FOD incident or accident falling into the first two screening levels will obviously require a higher level of effort and resources. Once the FOD problem has been screened, the FOD POC can then assign the appropriate resources (personnel and materials) and authority to begin the investigation.

3.2 Conduct Accident/Incident Investigation

Human factors should be an integral part of any investigation of any incident or accident resulting from FOD. The aviation industry is a complex system and rarely is a FOD incident/accident due to one element alone.

Whenever possible, investigators of a FOD incident or accident should conduct an on-site examination. This would include walks through the area of concern and interviews with personnel involved and other stakeholders. Though technically the data collection phase occurs at the beginning of an investigation, in reality it can run throughout the investigation.

Table 3. Significance Determination Levels With Associated Screening Characteristics

Significance Level	Screening Characteristics
Most Significant	Hazard to public health and safety
	Hazard or injury to maintenance personnel
	Major damage to aircraft or its components
	Major damage to maintenance equipment
	Violation of Federal Aviation Regulations
	Events reportable to regulatory authority (i.e., FAA)
	Significant impact on maintenance operations (shut down)
More Significant	Violation or organization's rules or management mandates
	Minor personal injury
	High potential to causing a serious safety event
	High risk / Low uncertainty
	Significant reduction in maintenance activities
	Minor damage to aircraft or its components
	Minor damage to maintenance equipment
Less Significant	Adverse trend in FOD occurrences

	Component failures due to FOD (depending on severity, may be a Most Significant Event)
	Inconsequential damage to aircraft or maintenance equipment
	Moderate immediate consequence
	Moderate learning opportunity
Trends	Poor audit results
	Easily correctable situation
	Tolerable risk
	Minor condition that requires no other action to evaluate

3.2.1 Human Factors Investigative Models and Tools

There are a number of human factors investigative models and tools described in the literature. The following is a brief discussion on several of the more common models and tools associated with the aviation maintenance environment.

3.2.1.1 MEDA

Maintenance Error Decision Aid (MEDA)5 is a tool developed by Boeing Commercial Airplane Group to investigate maintenance errors and to help organization reduce or eliminate these errors by redesigning procedures. Though MEDA may be included as a root cause analysis technique, it offers much more. As such, it is presented here as a model for the investigation of FOD incidents or accidents. MEDA provides a multi-page form with Contributing Factors Checklist that provides the investigator a clear path for identifying elements in the chain of actions leading to an error. As part of the selection of maintenance errors, MEDA allows for input on actions causing Foreign Object Damage.

MEDA is based on three main principles:

1. Mechanics don't intend to make mistakes.
2. Errors result from a variety of workplace factors such as unclearly written manuals, poor communication between workers, or improperly labeled parts.
3. Management can fix the factors that contribute to errors.

Based on these principles, MEDA provides a paradigm shift in incident/accident investigations from "Who caused the problem" to "Why did the problem occur." Only by understanding the root cause can the problem be eliminated.

In Section 3.2.2 of these Guidelines, the elements of a standardized FOD incident/accident reporting form are discussed. It is not the intention of these Guidelines to promote a universal form or the work of one group of individual, yet the MEDA form does provide a fairly comprehensive checklist. It can also be considered a model since it provides a framework for organizing and analyzing the data collected.

3.2.1.2 Dirty Dozen

Gordon Dupont developed the Dirty Dozen in his work with Transport Canada. Though not a model per se, the Dirty Dozen (see Appendix A) along with the examples and available safety nets provides an excellent tool for training, for situation awareness, and as a checklist of human factors issues in the aviation environment (Dupont, 1997)7.

3.2.1.3 SHEL Model

Originally created by Elwyn Edwards in 1972 and later modified by Frank Hawkins (1987)10, the SHEL model is systematic representation of human factors interfaces. Hawkins SHEL model described the human factors interfaces from a flight crew's perspective, but it is equally appropriate for other systems such as the aviation maintenance environment. It is an excellent tool to aid in the understanding of how the human interacts with the system. SHEL is an acronym for Software, Hardware, Environment, and Liveware (the human element of the system). A full description of this model may be found in a number of sources to include Human Factors In Flight (Hawkins, 1987)10 and Human Factors In Aircraft Maintenance And Inspection (ICAO, 1995)13.

The hub, or center, of the SHEL model is Liveware, which represents man. This human component is not precise as in hardware or machinery, but rather has variability around a norm. Before we can understand how man interacts and interfaces with the system, it is important to recognize all the characteristics (limitations, strengths, etc.) of the human. With this understanding of the human center, the SHEL model addresses the following interfaces:

- Liveware – Hardware Interface. Sometimes referred to as the man-machine interface (MMI), this interface matches the human characteristics with the hardware.

- Liveware – Software Interface. This interface includes the non-physical aspects of the system such as procedures, manuals, and even computer software.

- Liveware – Environment. In Hawkins' model this involves the adaptation of the environment to match human characteristic. In maintenance, the environment cannot always be modified for the complete comfort of the technician. Yet, it remains a critical human factors aspect that must be understood and evaluated.

- Liveware – Liveware. This interface represents the interaction between people as in teamwork or crew coordination. Though not mentioned by Hawkins, this portion of the model may also addresses the interface between the individual and the organization.

3.2.1.4 Pear Model

Though the SHEL model is widely known, a complementary model called the PEAR Model has been developed with a focus on the aviation maintenance environment. Dr. Michael Maddox developed the PEAR Model, which stands for People, Environment, Actions, and Resources, for a maintenance human factors course that has been presented worldwide.

Human factors analyses must first consider the human (People). Studying people includes such factors as the following: size, mental and physical capability, attitude, training, age, adaptability, and other such characteristics. It is imperative to understand people in order to proceed with good human factors analyses. "E" stands for Environment in which the people work. The environment is not limited to such physical measures as temperature, humidity, noise level, and illumination, but also to the organizational environment including such factors as labor contracts, management-worker cooperation, and workplace communication. "A" is for Actions, which people perform in the environment. Actions describe what the human must do to complete the variety of daily work tasks. Formalized methods for job task analysis (JTA) are important tools that human factors professionals use to define actions. JTA results help to create precise specifications for hiring, training, designing equipment and information, and determining all critical aspects of job performance. Finally, "R" is for the Resources that are necessary for people working in a defined environment to perform actions. Resources include such things as tools, computers, information, other people, time, and more. PEAR works well to understand and address all issues related to human performance in maintenance.

The important human factors aspects of the PEAR Model are provided in Appendix B. Though this model does not predict the behavior of the system, the checklist of items does provide a framework that organizes data and aids in the investigation of FOD incidents or accidents.

3.2.1.5 Human Factors Accident Classification System Maintenance Extension (HFACS-ME)

Recently, Schmidt and Watson (1999)21 reported on the HFACS-ME taxonomy for the classification of human factors causes of aviation maintenance related mishaps. The HFACS was developed by Naval Safety Center, and is an effective means of capturing the nature and relationships among latent and active failures. HFACS-ME can be used to uncover all levels of human error that contribute to an aviation maintenance mishap and proactively use this information for the development of human factors intervention strategies.

The HFACS-ME Model, which incorporates features from Heinrich's "Domino Theory" (1980), Edward's SHEL Model (1981), and Reason's Model on Human Error (1980),8,11,18 provides four classifications of human error (Supervisory Conditions, Maintainer Conditions, Working Conditions, and Maintainer Acts) with three maintenance error orders. The categories and orders are shown in Appendix C.

The HFACS-ME was originally developed for the military, but it is also effective in evaluating human error on safety in commercial aviation maintenance. As such, the Federal Aviation Administration, through the Office of Aerospace Medicine, has identified this model for use in the examination and analysis of commercial mishaps.

3.2.2 Standardized FOD Investigation Reporting Form

As previously mentioned, it is not the purpose of these Guidelines to provide a Foreign Object Damage Report form for use by the aerospace industry. Instead, each organization should develop a form to aid in FOD investigations and to organize data gather for later entry into a FOD database. Rather than adding to the current forms within the organization, it may be possible to use or modify an existing accident investigation report form. When designing or modifying a form, it is important to capture data that will be used in the selected root cause analysis technique. A list of data collection items is provided in Table 4. This list is not meant to be inclusive, but serves as a choice list of potential data fields. There are also a variety of data and information sources available to a person or team performing a FOD investigation. Table 5 provides a list of potential data and information sources along with the use and potential benefit.

Table 4. Potential Data Fields	
1)	Time of incident/accident
2)	Date (date of report, date of incident/accident, date discovered, etc.)
3)	Person making the report
4)	Location
5)	Shift
6)	Organization/Department
7)	Personnel involved at time of incident/accident
8)	Property/facility involved
9)	Direct Costs (hours, cost of parts, etc.)

10)	Injuries sustained
11)	Description of incident or occurrence
12)	Description of damage
13)	Immediate action taken
14)	Recommended or corrective action
15)	Photographs and drawings may be included to enhance the investigation report

Table 5. Additional Sources of Data for a FOD Investigation

Data Sources	Potential Use or Benefit
Inspection / Maintenance / Modification Records	These documents are an excellent source of information during a FOD investigation. It may provide information on what maintenance or modification was performed and whether the area was inspected prior to closing.
Vendors Technical Manuals / Drawings / specifications	These documents give insight and understanding of the aircraft's component where the FOD occurred. If there is an area that is susceptible to FOD yet has limited access, should inspection procedures be changed?
Training Records	Examination of training records may indicate whether individuals received FOD training and when. Also, efforts may reveal gaps in FOD training content
Procedures/workcards/work requests	These documents should be reviewed in light of the FOD event. Was guidance missing or were steps skipped to meet time constraints? For example, did the procedures or workcards that directed the capping of a line prior to maintenance include the removal and disposal of the cap?
Job Task Analysis (JTA)	The purpose of conducting a JTA is to identify and evaluate the steps necessary to conduct a task. JTA may also be used to modify task steps to prevent FOD.
Physical layout of the system	Physical layout means the localized area within which the FOD incident/accident occurred. It includes equipment availability and placement, staffing, environment (lighting, noise, temperature, etc.), and other physical aspects that may have influenced the event
Publications and guidance	These include Federal publications such as Advisory Circulars and Alerts; internal publications that share knowledge gained such as NAFPI newsletters and internal newsletter; and published FOD guidelines.
Work schedules	Fatigue may play an important role in the FOD event. Examination of the work schedules may reveal mental and physical fatigue due to extended work hours, back-to-back shifts, time constraints imposed by management, etc.
Experience with similar events	Never overlook your own experience or the experience of your co-workers. These experiences provide insight into potential solutions.

3.2.3 Data Entry Into Database

All data that is collected from the reporting form should be stored in a database for analysis. The primary purpose of this effort is to provide a benchmark from which to measure future improvements. The organization should implement a process of improving performance by continuously identifying, understanding, and adapting outstanding practices and processes found both inside and outside the organization. In creating this benchmark, the company focuses on exploiting “best practices” rather than just measuring best performance. As new concepts and ideas are tried, performance can be measured and compared, and this will result in improved processes.

Most organizations are willing to freely share information concerning their FOD prevention programs and processes. Some programs are narrow and deep and focus on specific elements of FOD prevention while other programs tend to general and cover broader aspects of FOD prevention. It is important, therefore, to know what processes and procedures you are looking for when you examine programs from external organizations.

Use of a database will also provide ability to sort and query by the fields within the database. Thus, it is important to design the database keeping in mind the queries and reports that need to be produced.

3.3 Analysis of Data – Root Cause Analysis

The current theme of accident investigation is to determine “why” the event occurred as opposed to “who” is to blame. According to William Rankin, PhD, Technical Fellow for Maintenance Human Factors at Boeing Commercial Airplane Group, “In most accidents it’s the process that’s to blame, not the individual worker.” Thus, it is vital to apply the time and effort to analyze the data and to identify the root cause of an event. The root cause may be defined as the basic reason for an undesirable condition or problem, which if eliminated or corrected would prevent it existing or occurring in the future (Wilson et al., 1993)25.

There are a number of steps that must be followed during in the application of a root cause analysis technique (Anderson and Fagerhaug, 2000)2, and the following lists the steps along with potential analytical tools that may be employed. It is important to realize that within each step of the process, there are a variety of tools available from very unstructured simplistic approaches to more complicated structured tools. Use of any particular analytical tool will be dependent on the situation or circumstances, and some tools may be used in more than one step. The investigating individual or team will need to fit the approach to the complexity of the problem while balancing the cost of the investigation against the potential loss or undesirability of the occurrence.

The following steps are presented under the assumption that the FOD incident or accident has been investigated and that the information and data has been assembled in a centralized location. The actual interviews and data collection is not a discrete element occurring only at the beginning of an investigation, but rather may continue throughout the analysis process as additional information is needed or warranted. Also, for each step, the analytical tools and procedures are listed with very little, if any, explanation. These tools and procedures are well documented, and a full description of each tool along with implementation procedures may be found in any number of text books dealing with quality control, total quality management (TQM), etc. such as Montgomery (1991) Wilson, Dell and Anderson (1993) and Anderson and Fagerhaug (2000)2,14,25.

Step 1: Identify and define the problem

Although this may sound overly simplistic, it is a crucial first step. The FOD investigation team must have a clear understanding of the problem. Are they merely looking at a symptom? Are there multiple problems? If there are multiple problems, then each problem must be defined and analyzed separately, and the team may be required to prioritize the problems. What was the active error that caused the event? Was there a latent error(s) that lead to the active error?

Tools may include:

- Intuition
- Personal Experience
- Brainstorming

- Nominal Group Technique (NGT)

Step 2: Understand the problem

No problem occurs in a vacuum. Therefore, it is important for the investigating individual or team to have a complete understanding of the system within which the event occurred. What people are involved and how do they interact and communicate? What is the environment in which they function? What actions are taking place (i.e., procedures or processes)? What resources are available or need to be available? At this point, the reader may recognize the application of the PEAR Model mentioned earlier.

Tools may include:

- Personal Experience
- Job Task Analysis (JTA)
- Flow Charts
- PERT chart or CPM
- Process charts
- Checklists

Step 3: Possible Cause Analysis

Once the problem has been defined and the team has an understanding of the system, then they can begin to analyze the information and data in order to identify the root cause of the FOD incident or accident. It is possible that an individual who intentionally deviated from the safe operating procedures, recommended practices, or rules, may have caused the problem. More than likely, however, the investigating team may find weaknesses in equipment design or availability, incorrect or out-of-date operational procedures, or lack of awareness and training deficiencies. They may even find that the root cause goes as far back as the culture of the organization or the lack of management support for FOD prevention.

Tools may include:

- Histograms
- Pareto Charts
- Cause and Effect Diagrams
- Scatter Diagrams
- Fault Tree Analysis

Step 4, Develop and Implement Corrective Actions, and Step 5, Implementation and Evaluation of Corrective Actions, are covered in the following major sections.

3.4 Develop and Implement Corrective Actions

The Corrective Action Plan (CAP) is a document developed by the FOD team that establishes the necessary measures and procedures to assure that the root causes leading to a FOD incident or accident are promptly and accurately identified and corrected. It is essential that the implementation of the CAP precludes the reoccurrence of the FOD incident or accident.

3.4.1 Corrective Action Plan Content

There is no standardized format for a CAP, but is should present a structured solution to correct or eliminate the root cause of the FOD event. Elements of the Corrective Action Plan may include:

- Documentation of the processes leading to the CAP including problem recognition and identification, screening, investigation procedures, and root cause analysis procedures used
- Detailed results of the investigation
- Results of the root cause analysis
- Identification of Human Factors causes and Human Factors intervention strategies
- Evaluation of alternative solutions
- Economic impacts
- Adherence to regulations
- Potential conflict with other groups or processes

For purposes of corrective action implementation and evaluation (see Section 3.5), the plan should also; provide specific goals or expectations, define the criteria to be used to measure its effectiveness, and describe any process that will be used to collect feedback.

The focus of the CAP should be on a single corrective action. If the root cause analysis reveals multiple causes, a separate plan should be developed to address each cause. Lumping the corrective actions together increases the difficulty of implementation and evaluation. Also, the more limited the scope of the CAP, the easier it is to implement and close. Global or enterprise wide CAPs require extensive coordination between groups and departments and will raise the implementation costs accordingly.

Table 6 provides a basic checklist to assure that the CAP covers key points. This checklist is a starting point and should be enhanced and modified based on experience and the specifics of the organization.

Table 6. Checklist For A Corrective Action Plan

	Checklist Items
q	**Is the Corrective Action Plan focused on one root cause?**
q	**Will the Corrective Action Plan correct the immediate problem?**
q	**Will the Corrective Action Plan prevent a reoccurrence of the problem?**
q	**Does the Plan address all the contributing factors?**
q	**Are the actions presented in the Plan properly sequenced?**
q	**Does the Plan identify the “Action Owners” who will implement the plan, and do they have the appropriate expertise?**
q	**Have the Action Owners been informed and assigned realistic completion dates?**
q	**Do all stakeholders understand the details of the Plan?**
q	**Is the Plan feasible with respect to costs, resources, time, etc.?**
q	**Does the Plan address the economic impact and benefits to the organization?**

q	**Is the Plan compatible with published regulations and organization directives?**
q	**Does the plan conflict with other plans or programs?**

3.4.2 Safety Aspects of Error

Examination of the literature on human error in the aviation maintenance environment indicates that errors (including FOD errors) can originate from two sources -- from the individual or from organizational factors (i.e., procedures, policies, etc.). It is important, therefore that the corrective action plan identify whether the root cause of the FOD is primarily attributable to an individual or whether it is can be traced to a system-induced error.

In analyzing and cross mapping three commonly used failure-factor taxonomies, Patankar and Taylor (2001)16, defined thirteen organizational factors and twelve individual factors that are the root causal factors in errors (see Table 7).

Table 7. Organizational and Individual Factors Leading to Maintenance Errors (Patankar and Taylor, 2001)[16]

Organizational Factors	Individual Factors
Hardware/Equipment/Tools/Lack of Resources/Not Enough Staff	Physical Health
Design/Configuration/Parts	Fatigue
Maintenance Management /Leadership /Supervision/Company Policy	Time Constraints
Work Processes/Procedures/Information	Pressure from Management
Error-enforcing Conditions/Norms/Peer Pressure	Complacency
Housekeeping	Body Size/Strength
Incompatible Goals	Personal Event/Stress
Communication Processes	Workplace Distracters
Organizational Structures/Corporate Change /Union Action	Lack of Awareness
Training/Technical Knowledge/Skills	Lack of Knowledge
Defenses	Lack of Communication Skills
Environment/Facility	Lack of Assertiveness
Lack of Teamwork	

Not all FOD errors are due to the individual, nor are all FOD incidents or accidents attributable to organizational causes. In the past, the focus of a FOD investigation was on the problem point or the individual where the active failure occurred. More recently, however, there has been a paradigm shift in FOD investigations to examine the relevant facts related to the event and to background causes or latent failures. Employing a structured and systematic approach to the investigation and root cause analysis will minimize any potential bias towards the individual in the corrective action plan.

Certain causal factors can be identified with either the organization or the individual. For example, lack of knowledge can be either an individual problem or a problem throughout the organization. Similarly, pressure from management can be systemic or individual. To categorize the causal factor, Reason (1997)[19] provides a test to determine if an error was due to the individual or was the result of an organizational factor. The error can be categorized as systemic if it was equally likely to be committed by another individual under similar conditions. Otherwise, it is due to individual factors.

Once the FOD error has been categorized, then the FOD team can correlate human factors elements and examine potential Human Factors intervention strategies for the Corrective Action Plan. To assist the FOD investigation team in identifying FOD intervention strategies, a table has been produced that relates error factors with Human Factors best practices (see Appendix D). The table design is a modification of work performed by Drury and Watson (1999)6 in detailing Human Factors good practices, and consists of three interrelated columns.

1. **Error Factors**: The error factors come from the list of factors provided in Table 7, and include both organizational factors and individual factors.

2. **Good Practice**: This column provides recommended prescriptive good practices for eliminating FOD from the maintenance environment. These good practices are presented as one sentence summary. Specific implementation steps and procedures are not within the scope of this document.

3. **Why?** This column provides a logical explanation as to why the good practices should be implemented or what benefits may be derived. The rationale behind each of the explanation come from research on Human Factors in Aviation Maintenance and Inspection performed for the Federal Aviation Administration, Office of Aerospace Medicine. This research is accessible at the following web site: http://hfskyway.faa.gov/document.htm

Some good practices are not solely for one particular error factor, but are pervasive throughout the system. Training, for example, appears many times as a prescriptive from both a technical perspective as well as a Human Factors perspective. Training to prevent FOD should provide knowledge and skills that are transferable in order to cross all organizational boundaries.

3.5 Implementation and Evaluation of Corrective Actions

Corrective actions should be implemented according to the specifications, schedule, costs, etc. outlined in the Corrective Action Plan document. Modifications may be made, but should be justified and communicated to the stakeholders. The appropriate group should perform the implementation with FOD POC having overall responsibility.

Once implemented, it is important to monitor and evaluate the CAP. The evaluation has two objectives:

1. **Short-term**: Has modifying or eliminating the root cause eliminated the immediate cause of the Foreign Object Damage?

2. **Long-term**: Has the implementation of this plan prevented all similar reoccurrences across the organization?

The following four guidelines are provided for the evaluation of the CAP (Thiagarajan, 1997)22:

1) Integrate the evaluation into other activities

Rather than setting up a special group to conduct evaluations of the CAP's effectiveness, combine the evaluation into the routine proactive measures. The FOD audits are an excellent way to evaluate effectiveness, but other tools may include such things as surveys and interviews with AMT and management as well as soliciting feedback as part of standing meetings.

2) Harness the power of teams

Soliciting feedback from groups as opposed to individuals may take more time and energy, but the results are worth the investment. Many times, groups will provide more valid and creative feedback.

3) Computerize all phases of the evaluation

The benefits of a database have been discussed in Section 3.2.3. In addition, the information in the computer can easily be graphically displayed for desktop publication as we as for presentations.

4) Get more out of less data

It isn't the quantity of data but the quality. It takes time and money to collect data and to analyze that data. Make sure you collect all the pertinent data in an organized fashion. Also, a well-designed database will allow for extraction of important information for analysis.

The elimination of FOD is a continuous improvement process. As such, the evaluation measures can benefit the aforementioned proactive activities. For example, lessons learned can help guide and tune future implementation processes, as well as help in developing a business case to expand the CAP to other parts of the organization. Finally, the evaluation measures can aid in the development of benchmarks for future comparisons.

3.6 Concluding Comments on Structured Reactive Measures

These guidelines promote a structured approach to reacting to a FOD incident or accident. By following this or other similar structured approach to analyzing the data and information collected during a FOD investigation, there are a number of benefits to the individual, the department and the organization as a whole. These benefits include:

- Objective problem solving - though intuition and personal experience play a part in arriving at the root cause of a problem, the tools and structure provided above should prevent the quick and easy fixing of symptoms. The end result of this analysis is to not only identify the root cause but to institute corrective actions that eliminate or prevent reoccurrence. Another benefit from the structured problem solving approach is that it aids in the identification, assembly, and integration of all the contributory circumstances to the problem.

- Identification of other potential problems – in the course of understanding the problem (Step 3), the investigating team may discover that processes or procedures with a root problem in one area of the organization may be replicated in another area. Solving one problem may lead to identifying potential problems in other areas. This allows for the elimination of a problem before it occurs.

- Identify improvement opportunities – another beneficial spin-off from understanding the problem comes from the JTA or flowcharts. During the analysis, the team may discover more effective and efficient procedures for accomplishing a task. In addition to a cost savings, there exists the opportunity to improve safety. As a corollary, evaluation of tasks and task procedures may yield the opportunity to enhance the utilization of existing resources.

- Avoid unnecessary disruption – with a standardized and structured approach to FOD incident and accident investigation, the investigation team can minimize or avoid unnecessary disruptions to the workflow.

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6 APPENDIX A - THE DIRTY DOZEN ERRORS IN MAINTENANCE AND SAFETY NETS (DUPONT, 1997[7])

1) **Lack of Communication** – this can be in the form of verbal or written communications or a combination of the two.

Safety Nets: Use of logbooks; worksheets, task cards, etc. to communicate and remove doubt; Discuss work that is to be done or what has been completed; Never assume anything.

2) **Complacency** – an insidious cause, which with the constant repetition of many similar maintenance inspections can cause or contribute to an error in judgment.

Safety Nets: Train yourself to expect to find a fault; Never sign off work you did not do (aka: “pencil whipping”)

3) **Lack of Knowledge** – with all of the new technology and changes, this cause is not that uncommon. When coupled with the “can do” attitude of most maintenance personnel, it becomes even more probable.

Safety Nets: Get training; Use up-to-date manuals; Ask a technical representative or someone else that knows.

4) **Distraction** – this cause is thought to be responsible for about 15% of all maintenance errors. One leaves a task (both physically and/or mentally) for any reason and returns thinking that he/she is further along with the task then they are.

Safety Nets: Always finish the job or unfasten the connection; Mark the uncompleted work; lockwire where possible or Torqueseal; When you return to the job always go back three steps; Use a detailed check sheet.

5) **Lack of Teamwork –** this cause is often tied in with lack of communication, but can be responsible for major errors. With maintenance often involving a multitude of workers, good teamwork becomes essential.

Safety Nets: Discuss what, who, and how the job is to be done; Be sure that everyone understands and agrees.

6) **Fatigue –** this is a very insidious cause because, until it becomes extreme, the person is usually unaware that he/she is fatigued. They are even less aware of what the effects of fatigue are.

Safety Nets: Be aware of the symptoms and look for them in yourself and others; Plan to avoid complex tasks at the bottom of your circadian rhythm; Sleep and exercise regularly; Ask others too check your work.

7) **Lack of Resources –** no matter who the maintainer works for, there are when there is a lack of resources and a decision must be made between ground the aircraft or let it go. The average maintainer is a “Can-DO” type of person and takes great personal pride in repairing aircraft. Thus the decision to be made can be difficult.

Safety Nets: Check suspect areas at the beginning of the inspection and AOG the required parts; Order and stock anticipated parts before they are required; Know all available parts sources and arrange for pooling or loaning; Maintain a standard and is in doubt ground the aircraft.

8) **Pressure –** few industries have more constant pressure to see a task completed. The secret is the ability to recognize when this pressure becomes excessive or unrealistic.

Safety Nets: Be sure that the pressure is not self-induced; Communicate your concerns; Ask for extra help; Just say No.

9) **Lack of Assertiveness –** the average AME/AMT is not an assertive person and most of the time his job does not require him/her to be. However, there may come a time when something is not right and he/she will have to be assertive in order to ensure that problem is not overlooked.

Safety Nets: If it is not a critical task, record it in the journey logbook and only sign for what is serviceable; Refuse to compromise your standards.

10) **Stress –** stress is a normal part of everyday life until it becomes excessive. The secret is to be able to recognize when it is becoming excessive.

Safety Nets: Be aware of how stress can affect your work; Stop and look rationally at the problem; Determine a rational course of action and follow it; Take time off or at least have a short break; Discuss it with someone; Ask fellow workers to monitor your work; Exercise your body.

11) **Lack of Awareness –** this often occurs to very experienced maintenance personnel who fail to think fully about the possible consequences of work they are doing. Manuals do not cover the failure and after the fact one will often hear that common sense should have told you that.

Safety Nets: Think of what may occur in the event of an accident; Check to see if your work will conflict with an existing modification or repair; Ask others if they can see any problem with the work done.

12) **Norms –** this last cause is a powerful one. Most everyone wants to be considered one of the crowd and norms develop within such a group that dictates how they behave.

Safety Nets: Always work as per the instructions or have the instructions changed; Be aware that “norms” don’t make it right.

7 APPENDIX B - PEAR MODEL

***P*eople *E*nvironment *A*ctions *R*esources (PEAR)**

PEOPLE – Who

- Physical Factors
  - Physical characteristics
  - Sensory limitation
- Physiological Factors
  - Nutritional factors
  - Health
  - Lifestyle
  - Fatigue
  - Drugs

INCAPACITATIONS

- Psychological Factors

WORKLOAD

  - Experience
  - Knowledge
  - Training
  - Attitude
  - Mental or emotional state
- Psychosocial Factors
  - Interpersonal conflicts
  - Personal loss
  - Financial hardships

ENVIRONMENT – Where

- Physical
  - Weather
  - Location inside/outside
  - Workspace
  - Shift
  - Lighting
  - Noise
  - Safety
- Organizational
  - Personnel
  - Supervision
  - Union Management relations
  - Pressures
  - Crew structure
  - Size of company
  - Profitability
  - Morale
  - Culture

ACTION - What

- Steps
- Performance
- Number of people involved
- Communication
  - Oral
  - Visual
  - Written
- Information Control Requirements

RESOURCES – What and Who

- Procedures/Work Cards
- Manuals/Bulletins/FARs
- Test Equipment
- Hand/Power Tools
- Machine Tools
- Computers
- Paperwork/Signoffs
- Ground Handling Equipment
  - Forklifts/Tow Motors
  - Ladders/Steps/Work Platforms
  - Cranes Hoist/Jacks
- Fixtures
- Materials
- Task Lighting
- Manpower

	Training

8 APPENDIX C - ERROR CATEGORIES OF THE HFACS FRAMEWORK (SCHMIDT AND WATSON, 2001[21])

First Order	Second Order	Third Order
Supervisory Conditions	Unforeseen	Hazardous Operations Inadequate Document
	Squadron	Inadequate Design Inadequate Supervision Inappropriate Operations Uncorrected Problem Supervisory Violation
Maintainer Conditions	Medical	Mental State Physical State Physical/Mental Limitations
	Coordination	Communication Assertiveness Adapt/Flexibility
	Readiness	Prep/Training Qualification/Certification Violation
Working Conditions	Environment	Lighting/Light Exposure/Weather Environmental Hazards
	Equipment	Damaged Unavailable Dated/Uncertified
	Workspace	Confining Obstructed Inaccessible
Maintainer Acts	Error	Attention Memory Rule/Knowledge Skill

	Violation	Routine Infraction Exceptional

9 APPENDIX D - DETAILED HUMAN FACTORS GOOD PRACTICES FOR FOD ERROR PREVENTION

Organizational and Individual Error Factor	Good Practice	Why
• Hardware / Equipment / • Tools / Lack of Resources / • Insufficient Staff	• Order and stock anticipated parts before they are required • Establish staffing pool for maintenance personnel	• Lack of resources is one of the four major causes of systemic errors • Lack of items will cause delays • Short cuts are used to bypass lack of resources and can lead to FOD errors
• Design / Configuration / • Parts	• Color code for simple, reliable assembly • Provide better target / background contrast, for higher probability of detection	• Contrasting color on parts and packaging allows for easier identification and cleanup of FO
• Maintenance Management / • Leadership / Supervision / • Company Policy	• Provide training in: • Management • Leadership • Communication • Teamwork (MRM) • Provide maintenance managers The Human Factors Guide for Aviation Maintenance	• Training in management and teamwork improves and strengthens the safety culture of an organization • The Human Factors Guide for Aviation Maintenance was designed for use by maintenance managers have subjects such as: • Shiftwork and scheduling • Workplace safety • Training • Work Design • Sexual harassment • Disabilities • Etc.
• Work Processes /	• Institute standardized	• Lack of processes and

• Procedures / Information	and detailed work processes	procedures lead to guesses, shortcuts, increased likelihood of errors, lack of awareness, and teamwork degradation. All of which leads to an increased likelihood of a FOD accident • Standardize processes allows for repeatability and continuous improvement of FOD program
• Error-enforcing Conditions • Norms / Peer Pressure	• Provide unambiguous solutions to problems through proper communication • Provide training to AMTs and managers on norms and peer pressure • Provide training on proper communication techniques • Use OJT to communicate positive norms to new employees	• Ambiguous solutions potentially lead to negative behavior and deviations from standard procedures • AMT and managers are vulnerable to workgroup pressures and poor communication which negatively impacts the safety culture • New employee must be incorporated into the safety culture and be part of the FOD prevention program
• Housekeeping	• Institute good housekeeping procedures	• Good housekeeping procedures is a major element of a FOD prevention program (see Section 2.4 of these Guidelines)
• Incompatible Goals	• Provide training on establishing goals as part of teamwork training	• Creates conflict and interference from parties attempting to attain a goal and diminishes safety culture of organization
• Communication Processes	• Provide training on proper communication techniques • Reduce background noise levels • Redesign work cards with simplified English • Support proper shift change procedures	• Two way communication with feedback is essential to prevent latent FOD errors • Miscommunication and misunderstanding will most likely lead to FOD errors • Clearly written communications will facilitate tasks procedures and decrease potential of FOD
• Organizational	• Change the	• Positive changes in the

Structures /Corporate Change / Union Action	organization to improve the role and stature of the AMT • Provide leadership training to effectively utilize organizational changes • Encourage and involve the Union in order to gain support for organizational changes • Use the Union for upwards communication to management	organizational structure can affect the role of the maintenance technician and can produce measurable improvements performance and morale • Opportunity to gather Union support of FOD prevention program • Safety-significant information might be identified at union gatherings
• Training / Technical • Knowledge / Skills	• Provide FOD training as part of technical training (see Section 2.3.1)	• By adding FOD training, it becomes a part of the maintenance process and the safety culture
• Defenses	• Institute proactive safety measures as defense against errors	• Proactive FOD measures are more cost effective than reactive measures

• Physical environment / Facility	• Reduce noise levels
	• Use SHEL Model to evaluate environment
	• Provide adequate lighting for tasks
	• Provide lighting that does not give hot spot in field of view
	• Keep light levels fairly even throughout the work areas
	• Provide hydration, rest, portable cooling systems, proper scheduling, to mitigate the high temperature high humidity working environment
	• Provide proper clothing in colder climates
		• High noise levels interfere with communication
		• Loud noise causes hearing loss
		• SHEL Model is an effective tool for FOD investigations (see Section 3.2.1.3)
		• Inadequate lighting results in:
		  • Poor FOD detection results
		  • Task performance degradation
		  • Diffuse, shadow-free, glare-free illumination in all areas of a facility used by people improves performance
		• High temperatures and high humidity degrades performance and increases likelihood of FOD incident or accident

		• When body temperature is its lowest, people are most prone to error-caused accidents • Alertness, reaction time, performance levels decreases as body temperature decreases
• Lack of Teamwork	• Provide teamwork training on principles, skills, and benefits of teamwork • Implement MRM training • Encourage teamwork through OJT	• Good teamwork helps AMT to meet FOD maintenance goals effectively • Reduces potential latent and active FOD errors
• Physical Health	• Monitor physical health of employees	• Decrease in physical health (including sight and hearing) is an indicator of: • Peer pressure • Personal events (divorce, death in family, etc.) • Fatigue • Increase in workplace distracters • The presence of any of these indicators will increase the potential for a FOD incident or accident
• Fatigue	• Reduce number of back-to-back shifts • Standardize time on duty and minimize overtime • Suggest change of lifestyle to increase sleep time	• Effects of fatigue on safety are well recognized • Fatigue is cumulative and effects build day to day • Fatigue causes a decline in cognitive performance which is critical for recognizing and acting on potential FOD • Other results of fatigue that can negatively influence a FOD prevention program include: • Loss of motivation and initiative • Loss of reasoning

		• Loss of short term memory • Reduced decision making capacity
• Time Constraints and Pressure from Management	• Introduce time pressure reduction procedures • Evaluate critical procedures to add additional manpower • Understand human limitations • Develop a culture wherein it is allowed to ask for help	• May cause friction between groups and loss of teamwork • Increases likelihood of fatigue (see Fatigue) • Introduces opportunity for errors of omission • Maintenance personnel more likely to use shortcuts to save time which may result in additional FOD errors • Time constraints and pressure from management will adversely affects safety culture of organization
• Complacency	• Set standards for effective communication • Improve communication between organization and members • Address complacency through MRM • Provide more interaction • Reduce excessive automation	• Complacency leads to degradation in vigilance and situation awareness • Complacency may be caused from stress, overconfidence, or boredom. All of which will adversely affect the safety culture • Too much reliance on automation to find FOD problem causes complacency
• Personal Event / Stress • (external to work environment)	• Provide training to managers to recognize personal stress in employees • Provide stress management training • Allow time off to deal with personal stressors	• Personal stress may lead to health problems which can adversely affect job performance (see Physical Health Factor) • Stress from personal events may lead to a decrease in work performance and increase in potential FOD • Personal stress may lead to loss of sleep and resulting increase in fatigue at work (see Fatigue Factor)

• Workplace Distracters	• Provide detailed work instructions so that one can return to work where it was left off • Provide training on how to deal with distracters	• Workplace distractions are estimated to cause 15% of maintenance errors • When returning to work, one thinks he/she is further along then actual. This may result in cleaning up FO, leaving tools, parts, or equipment in an airworthiness area
• Lack of Awareness	• Provide situation awareness training • Reduce fatigue (see Fatigue) • Provide shared mental model • Verbalize decisions • Seek and provide feedback	• Common maintenance errors involved loss of situation awareness among different individuals • Loss or lack of awareness increases FOD potential by: • Degrading teamwork effectiveness • Omitting task steps • Misinterpreting or losing critical information
• Lack of Knowledge	• Provide technical training and maintain training records • Utilize OJT • Assure that detailed guidance is available	• Technical training will prevent guessing on procedures • Lack of training will cause a failure to complete a job correctly, and will lead to FOD accidents • Training prevents improper use of tools and equipment and likelihood of FOD incident or accident
• Lack of Communication Skills	• Provide training in both written and verbal communication skills • Utilize logbooks, worksheets task cards, etc.	• Lack of, or poor, communications is a major source of errors in the aviation maintenance environment • Good communication skills is important to the overall success of any FOD program • Feedback is a communication skill and is important in involving personnel in FOD prevention
• Lack of Assertiveness	• Provide assertiveness training	• Assertiveness can have a positive impact on safety and

	• Allow individuals to be assertive	dependability • Assertiveness is an effective skill to improve team behavior